1991

# High frequency audiometry: sound suite versus hospital room

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# *HIGH-FREQUENCY AUDIOMETRY: SOUND SUITE VERSUS HOSPITAL ROOM*

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MAY 10, 1991
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The present study was designed to assess and compare high-frequency audiometric thresholds obtained under two listening environments: a sound suite and a typical hospital room. A commercial high-frequency audiometer (Interacoustic AS10HF) with Koss HV/1A supraural earphones was used in the testing. Twenty-five subjects with normal hearing were evaluated using the modified Hughson-Westlake threshold procedure for frequencies from 8 kHz to 18 kHz. Each subject was tested in two 1-hour sessions. During the first session, subjects were evaluated in the sound suite and the hospital room. The second session consisted of a re-evaluation of hearing thresholds in the same hospital room the subject was evaluated in during the first session. This was done to determine the test-retest reliability of high-frequency thresholds in the hospital room.

The mean threshold differences measured in a hospital room, where the ambient noise level did not exceed 42 dBA SPL, is comparable to those measures obtained in a sound suite. The data also suggests that high-frequency audiometric thresholds obtained for repeated hospital room tests using the procedures outlined above are within $\pm$10 dB.

## Introduction

### Rationale for use of high-frequency audiometry

The use of high-frequency audiometry for detecting ototoxicity has been investigated for over twenty years. Jacobson, Downs, and Fletcher (1969) first reported that ototoxicity could be identified two months earlier using high-frequency monitoring rather than standard audiometric testing. Dreschler, van der Hurst, Tange, and Urbanus (1985) examined thresholds from 250-20,000 Hz for patients treated with an ototoxic drug and discovered that in 68% of the cases ototoxicity started in the 10-20 kHz region. In a follow-up study, high-frequency (10-20 kHz) threshold damage due to ototoxicity was again shown to be present before low-frequency (1-8 kHz) damage and was 15-20 dB greater (Dreschler, van der Hurst, Tange, and Urbanus 1989). Tange, Dreschler, and van der Hurst (1985) monitored patients as they were treated with an ototoxic drug (cis-platinum). A change in hearing thresholds ocurred in 35% of the patients monitored. In all instances of decreased thresholds, the threshold shift first ocurred above 8000 Hz. Fausti, Frey, Henry, Knutson, and Olsen (1990) concluded that the benefits of using high-frequency audiometry for ototoxic monitoring "...represents a mandate for its application" (p. 170).

### Problems encountered in high-frequency audiometry

The two major problems encountered in high-frequency audiometric testing which have hindered its use are:

- Coupling of the high-frequency transducer to the outer ear, and
- Providing an accurate calibration procedure for delivering high-frequency signals.

The difficulty in coupling the transducer to the outer ear and developing an accurate calibration procedure in high-frequency audiometry is due to standing waves. In audiometric air-conduction testing when one-quarter wavelength of the test frequency equals the distance from the transducer to the tympanic membrane, standing waves may occur. Generally, this will occur in the 6,000 to 8,000 Hz region in standard audiometric testing and appears as an elevated threshold. The standing wave problem can be corrected by adjusting the headphone, thus changing the distance of the ear canal and shifting the standing wave away from the test frequency (Durrant and Lovrinic, 1984). However, when attempting to test at even higher frequencies near 15,000 Hz other radial and circumferential resonant modes present themselves. This creates a condition such that the wavefront striking the tympanic membrane is a plane wave.

Methods used in coupling of the high-frequency transducer and calibration of the high-frequency signal

Osterhammel and Osterhammel (1977) developed a quasi-free field technique to remove the variability of coupling resonances caused by earphone placement in high-frequency audiometry. The transducer in this system is a dynamic speaker. The speaker is supplied with a conical plastic device to concentrate the sound and an L-shaped metal screen which guides the sound into the subject's ear, which is carefully positioned in relation to the speaker system. This method allows sound to be delivered to an uncovered ear and therefore take advantage of the acoustic characteristics of the concha and ear canal (Osterhammel and

Osterhammel, 1985). The calibration of the free-field was done with the use of a cylindrical PVC coupler. The coupler is situated in the field at the same point as the subject's ear during testing. This system has been shown to have test/retest reliability at all frequencies with a correlation coefficiant greater than 0.9 (Osterhammel, Osterhammel, and Terkildsen, 1979). Although the use of this system in a clinical situation has been proposed, DeSeta, Bertoli, and Filipo (1985) found headphone systems to be preferable over the free-field transducer in clinical situations because of the less complex technical equipment, time needed for testing, and attenuation of environmental noise provided by the headphone system.

Tonndorf and Kurmann (1984) developed an electro-stimulation technique which uses an electrical stimulus rather than an air-conducted tone. In this system, an audio signal is used to amplitude modulate a high-frequency carrier. This AM signal is fed to a conventional interrupter switch and attenuater arrangement, then to an amplifier, and finally to a pair of stainless-steel mylar-coated electrodes. These electrodes are attached to both mastoids for bilateral testing. Tonndorf and Kurmann maintain that calibration of the electro-stimulation system is built into the testing procedure by obtaining the test results in milliamperes. They proposed that this technique could eliminate the acoustical difficulties found at high-frequencies in air-conduction methods. Okstad, Laukli, and Mair (1988) compared electric bone conduction and air conduction thresholds at high-frequencies and found that the reproducibility is similar in both procedures. However, there was a gap between the air-conduction and electric bone conduction thresholds, which raises the question of the nature of the pathway which is carrying the electrical signals.

In 1979, Fausti, Frey, Erickson, Rappaport, and Cleary developed a new high-frequency test system which provided advances in coupling of the transducer and calibration of the system. The development of a dynamic headset with a ceramic diaphragm, Koss HV/1A, provided a transducer which a) could be driven at 8V rms b) provided a flat frequency response for 8-20 kHz and c) could be coupled to the subject's head in a conventional manner. A coupler to calibrate the Koss HV/1A earphones was specifically designed to measure frequencies in the 8,000-20,000 Hz range. This coupler is constructed of RTV silicone rubber and consists of a 1/2 inch condenser microphone which fits into the center of the cavity. The coupler is 6cc in volume. This calibration procedure is similar to that used in conventional audiometric systems. The reliability of this system was found to have an overall mean threshold difference across frequencies of 3 dB (Fausti, Frey, Erickson, and Rappaport 1979b) The validity of this system has also been documented through a release-from-masking of narrow bands of noise on high-frequency stimuli experiment which revealed that the response of a subject to high-frequency stimuli is the result of the high-frequency tone and not the perception of a lower frequency distortion product (Fausti, Rappaport, Schechter, and Frey 1982).

Since the development of the Fausti et al. prototype, several high-frequency audiometers have become commercially available. Laukli and Mair (1985) have shown that a commercially available high-frequency audiometer, the Demlar 20k, which is based on Fausti's prototype has approximately the same degree of reproducibility as conventional

audiometry. They found that while threshold data between subjects is highly variable, intrasubject reliability is consistent over time. Test/retest reliability has also been demonstrated to be within ±10 dB in a sound suite using the Interacoustics AS10HF by Valente, Goeble, and Valente, 1989.

Current use of high-frequency audiometry

Despite the development of commercial high-frequency audiometers, very little research has examined the reliability of high-frequency audiometry outside a sound suite. Consequently, the use of high-frequency audiometry is often hampered by the assumption that patients must be transported to an audiologic sound suite to obtain reliable results. Thompson and Northern (1981) include bedside testing in their "University of Colorado Protocol for Audiometric Monitoring of Patients on Ototoxic Drug Therapy", but only recommend testing from 250-8,000 Hz due to the lack of data on the use of high-frequency thresholds outside the sound suite.

The current high-frequency audiometers being used in clinical situations are now small and light-weight enough to be transported into a hospital room. Therefore, these high-frequency audiometers could be used for bedside testing if proven reliable.

Ambient noise level in the high-frequency range

The primary concern of testing outside a sound-suite has always been the noise floor. Specifications for permissible noise floor measures have been defined for audiometric screening (American Speech and Hearing Association Guideline for Identification Audiometry, 1975) and threshold estimates (American National Standards Institute Criteria for

Permissible Ambient Noise During Audiometric Testing, 1977), The ASHA Guidelines for Identification Audiometry gives the allowable ambient noise levels in the region of the test tone for frequencies from 500-4000 Hz. Although, the guidelines only specify noise levels up to 4000 Hz, the allowable ambient noise levels increase as the test frequency increases. This report also states that ambient noise is generally weak above 1000 Hz. The ANSI Criteria for Permissible Ambient noise during Audiometric Testing, also, lists acceptable noise levels through 8 kHz, with the highest level of ambient noise being at 8 kHz.. The criteria does state that the elimination of all ambient noise is not necessary for audiometric threshold testing.

The purpose of this study is to evaluate the differences in high-frequency hearing (8,000-18,000 Hz) measured in a sound suite and in a hospital room. The mean difference of high-frequency thresholds between the two hospital room test sessions (test and retest) and the magnitude of the test minus retest threshold differences will also be examined. Sound level meter measurements using a 1/3 octave band filter will be taken in the high-frequency range to determine the level of ambient noise in this region. It is hypothesized that no significant differences will be detected between thresholds established in a sound suite and a hospital room, mean threshold differences between the 2 hospital room test sessions will not be significantly different, and the magnitude of threshold differences will be within $\pm$10 dB for at least 90% of the cases.

## METHOD

### Subjects

Twenty-five otologically normal adults aged 21-25 years served as the subjects for this experiment. Each subject had binaural audiometric air-conduction thresholds of $\leq$15 dB HL for frequencies from 250-8000 Hz (re: ANSI-1969), a negative case history for ototoxic drug use, and a negative case history for noise exposure.

### Procedure

A commercially available high-frequency audiometer, the Interacoustics AS10HF, with Koss HV/1A supraural earphones was used in the testing. The earphones were fitted by the same experimenter for each subject. The earphones were placed so that the diaphragm was centered over the opening to the ear canal. The modified Hughson-Westlake threshold procedure was used to test the frequencies 8, 10, 12, 14, 16, and 18 kHz. Fausti et al. (1979b) compared the modified Hughson-Westlake threshold procedure with a two-alternative forced choice psychophysical method to determine the validity of a standard clinical procedure to test frequencies from 8-20 kHz. The study found that the modified Hughson-Westlake procedure is a valid and feasible clinical measurement for the high-frequency region. Therefore, the modified Hughson-Westlake threshold procedure was chosen due to its practical clinical application. Threshold testing began at a level believed to be loud enough for the subject to respond. If no response occurred then the level was increased in 10 dB steps until a response occurred. Once the first response occurred, the presentation level was decreased in 10 dB steps until no response

occurred and then increased in 5 dB steps until the subject responded. Threshold was obtained when the subject responded to 3 out of 5 presentations at the same level. Standard clinical instructions for threshold testing were given to each subject. Pulse tones were used to evaluate the right and left ear of each subject. The order of ears was randomized across subjects between the left ear first for all frequencies at each test session and the right ear first for all frequencies at each test session.

Each subject was tested in two 1-hour sessions. During the first session, each subject was evaluated in the sound suite and in a hospital room. Half of the subjects were tested in the sound suite followed by the hospital room, and the other half were tested in the hospital room followed by the sound suite. The second session consisted of a re-evaluation of hearing thresholds in the same hospital room the subject was evaluated in during the first session. Sound suite, hospital room ( HR test), and hospital room (HR re-test) thresholds were obtained for each subject at each frequency.

Noise level measurements were performed following the noise level measurement procedures set forth in the ANSI Criteria for Permissible Ambient Noise During Audiometric Testing (1977). A 1/3 octive-band sound level meter was used to measure sound pressure levels between 8,000-12,000 Hz. The limit of the sound level meter was reached at 12,000 Hz.

Since no standards have been developed for high-frequency audiology, some general guidelines on this matter were followed. The

AS10HF can be delivered with two types of calibration, SPL or HL. The HL values are derived from a study by Fausti et al. (1979b), but there is still a lot of ongoing research for the development of HL normative values. Therefore, the present study chose to calibrate in dB SPL.

The calibration of the AS10HF is similar to that of standard audiometers, except that the use of special high-frequency equipment is required. A 1/2" microphone from B&K type 4134 is is used with a high-frequency coupler the CHF-10. The calibration procedure is as follows: Connect the microphone and coupler to a sound level meter and place the earphone on the coupler. Place the clamp on top of the earphone so its metal ring is resting on the guides of the coupler. Present a 110 dB SPL tone to the earphone on the coupler and adjust the level by the potentiometer of the corresponding frequency. The desired values are listed in Chart 1. This procedure is done for each frequency and each earphone.

## Results

The obtained thresholds were analyzed to determine if there were significant differences in (1) the mean threshold measurements from the sound suite versus the means of HR test and HR retest (2) the mean threshold measurements of HR test versus HR retest and (3) the magnitude of the test minus retest threshold differences from HR test to HR re-test for the right and left ear separately. The measures for each subject from each ear at the six frequencies within the two test locations are inter-dependent. To jointly analyze the correlated variables, multivariate analysis techniques were used in the data analysis.

The comparison of the thresholds between the sound suite and the mean of the hospital rooms revealed no significant differences at the .05 level. Figure 1 illustrates the mean thresholds in dB SPL for the sound suite (booth) compared to the mean of HR test and HR retest across subjects and across ears for each of the test frequencies. The differences ranged from the smallest difference of .2 dB at 12 kHz to the largest difference of 1.9 dB at 16 kHz. These values show that there are no differences in high-frequency threshold testing between the two environments.

The mean differences between the thresholds of HR test versus the thresholds for HR retest across subjects and across ears is illustrated in Figure 2. This figure shows the mean threshold in dB SPL for Hr test and HR retest for each of the test frequencies. The difference in the mean thresholds between the rooms range from the smallest difference of .2 dB at 12 kHz to the largest difference of 2.7 dB at 16 kHz. The difference of

mean thresholds across all frequencies was not significantly different at the .05 level. Therefore, the use of repeated high-frequency threshold tests in hospital rooms produces consistent results across subjects.

The thresholds obtained in HR test minus the thresholds in HR retest is illustrated at three threshold difference levels. This is illustrated as the percent of cases which had test minus retest differences of ±0 dB, ±5 dB , ±10 dB. These values are graphed for the right ear in Figure 3 and for the left ear in Figure 4. The right ear is within the ±10 dB criterion level for greater than 90% of the cases for all frequencies, except 16 kHz. The ±0 dB and ±5 dB difference levels reveal wide variations across frequencies. The ±0 dB level was obtained for 60% of the cases at 8 kHz and less than 20% at 16 kHz. The ±5 dB criterion has a narrower range of variation across frequencies, but drops as low as 60% of cases at 16 kHz. The left ear, shown in Figure 4, has a similar variation between frequencies. The targeted ±10 dB level was obtained in 92% of the cases for all frequencies, except 18 kHz. The ±0 dB criterion is obtained in 68% of the cases at 12 kHz and drops to 32% at 14 kHz. The ±5 dB difference level ranges from 64% at 18 kHz to 94% at 12 kHz. These findings indicate that test versus retest threshold differences are within the established criterion of ±10 dB at each frequency in either one or both ears.

## Discussion

This study assessed and compared high-frequency audiometric thresholds in two listening environments, the sound suite, which has been proven reliable, and a hospital room. Due to the lack of data on high-frequency testing outside the sound suite, the study examined mean threshold differences between the booth and the hospital room, mean threshold differences between the HR test and HR retest sessions in the hospital room, and the magnitude of the test/retest threshold differences for the hospital room.

The study revealed that high-frequency threshold testing can be used in a hospital room with the same degree of reliability as high-frequency threshold testing in a sound suite. The mean differences between thresholds of HR test and HR retest revealed that there is no significant change in thresholds across frequencies between test sessions. These high-frequency thresholds were within the established criterion range of $\pm$10 dB for at least 90% of the cases at each frequency in either one or both ears. It should be noted that 16 and 18 kHz were below the $\pm$10 dB criterion for the right and left ear respectively. Therefore, the reliability of these upper two frequencies may be questionable for use in ototoxic monitoring.

Another interesting aspect of this study is the comparison of the obtained high-frequency thresholds with other research studies. The direct comparison of high-frequency thresholds across studies is difficult due to differences in instrumentation, calibration, and subject age. This fact is one of the major hindrances in the development of normative data

on high-frequency thresholds. The thresholds obtained in this study do agree with the pattern of increasing threshold values as frequency increases as found in a number of other studies (Zilis and Fletcher, 1966; Harris and Meyers, 1971; Fausti et al. 1979a; Schechter, Fausti, Rappaport, and Frey, 1986). Figure 5 shows the mean thresholds found in this study and those found in Schechter et al. (1986) which had subjects ages 21-25 and used Koss HV/1A earphones, which is congruent with the present study. As Figure 5 shows, the thresholds from the two studies are comparable, with the present study having thresholds consistently greater than the Schechter et al. study. The differences in the thresholds are less than 5 dB, out to 18 kHz. The slight differences in thresholds could be due to differences in calibration and/or instrument type. The similarity in thresholds between the present study and the Schechtler et al. study provides a basis for further research on the development of normative data with controlled instrumentation and subject age.

The reliability of the obtained thresholds has implications for bedside ototoxic monitoring. The utility of high-frequency audiometry in monitoring ototoxicity has been proven. However, the use of bedside monitoring has only been used and recommended for the conventional audiometric range (250-8,000 Hz). The results of this study suggest that high-frequency audiometry can be used reliability in bedside testing. Therefore, the usefulness of high-frequency ototoxic monitoring is maximized for a seriously ill patient.

Before the conclusion of this study, the limitations of this study must be noted. First, the subjects were healthy college-age people. The results

of the testing may be influenced by the age and health status of the individual. Second, the tests were done in private rooms without specialized hospital equipment in operation. These factors could influence the noise floor, and therefore the obtained thresholds. Future research examining these variables would be useful in the development of a standardized protocol for bedside high-frequency audiometric testing for monitoring ototoxicity.

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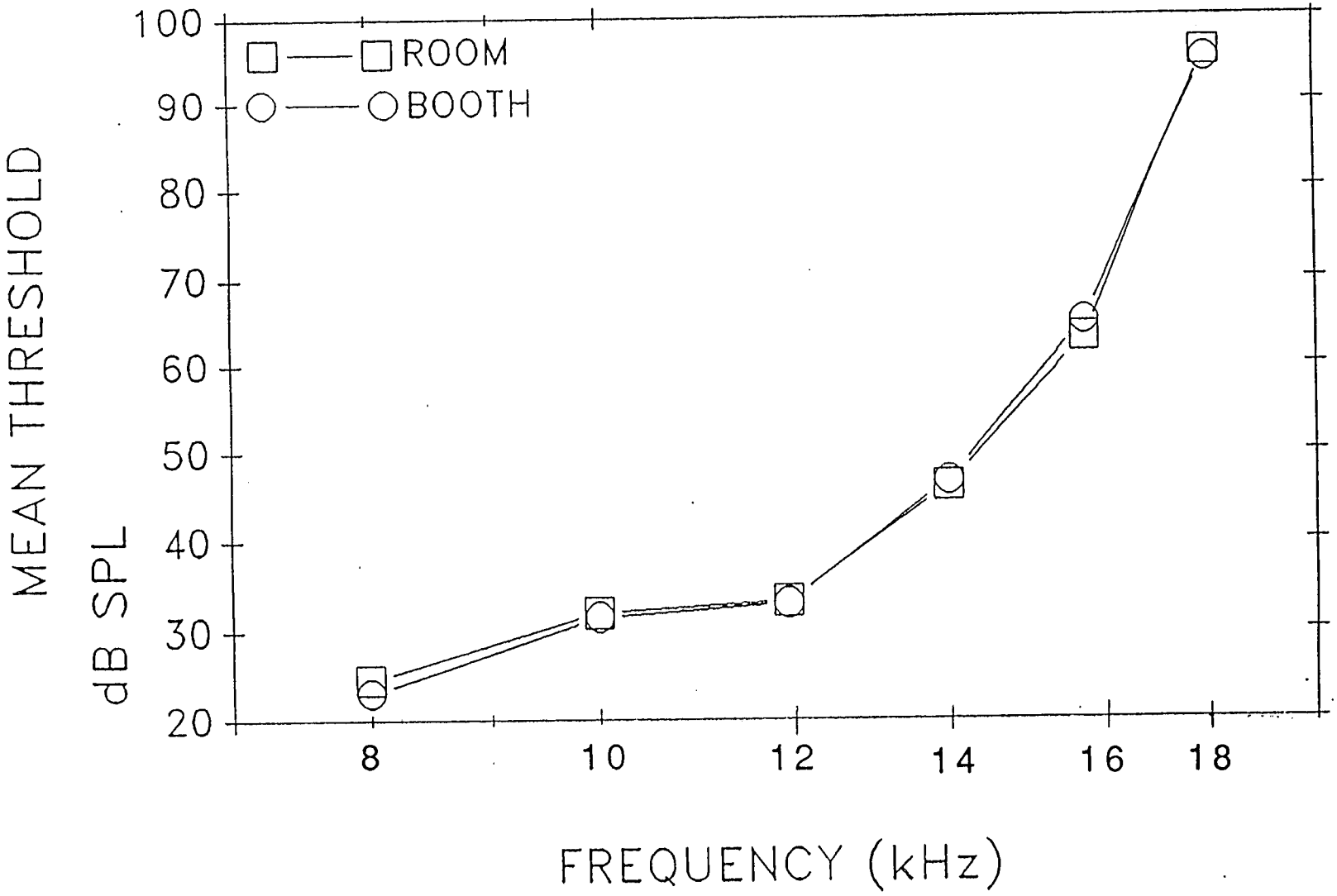
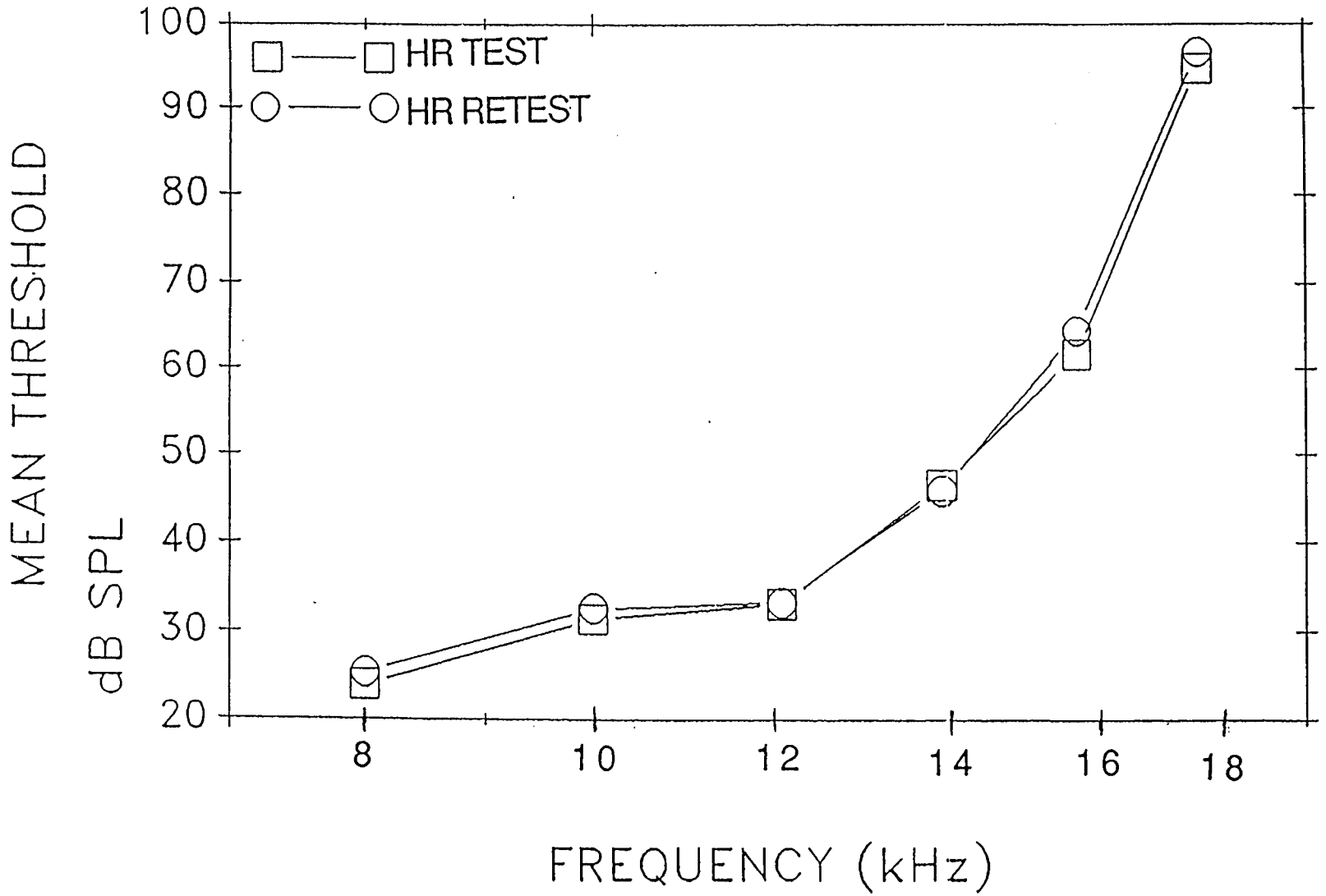
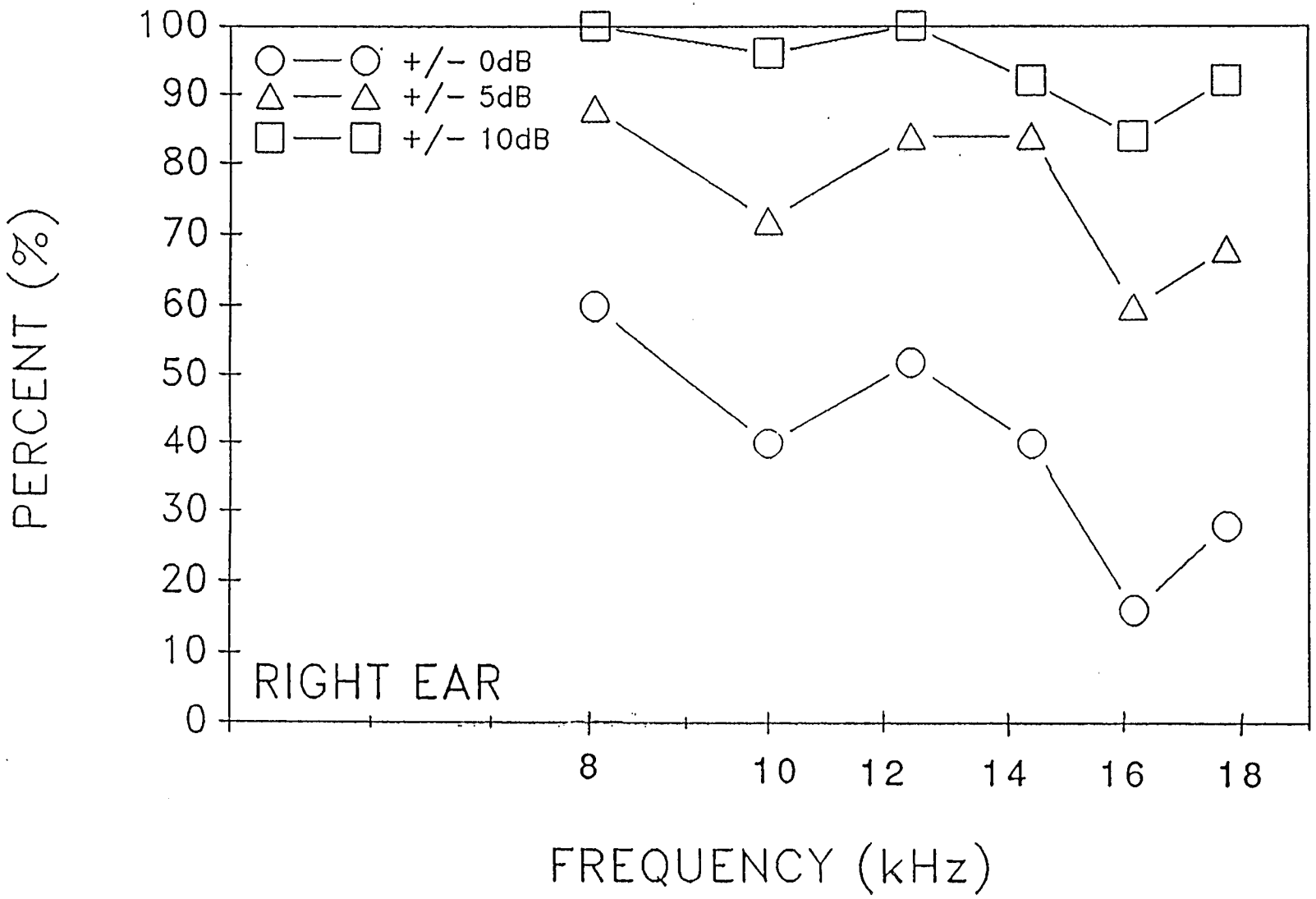
# FIGURE 1: MEAN THRESHOLDS OF HOSPITAL ROOM AND SOUND SUITE



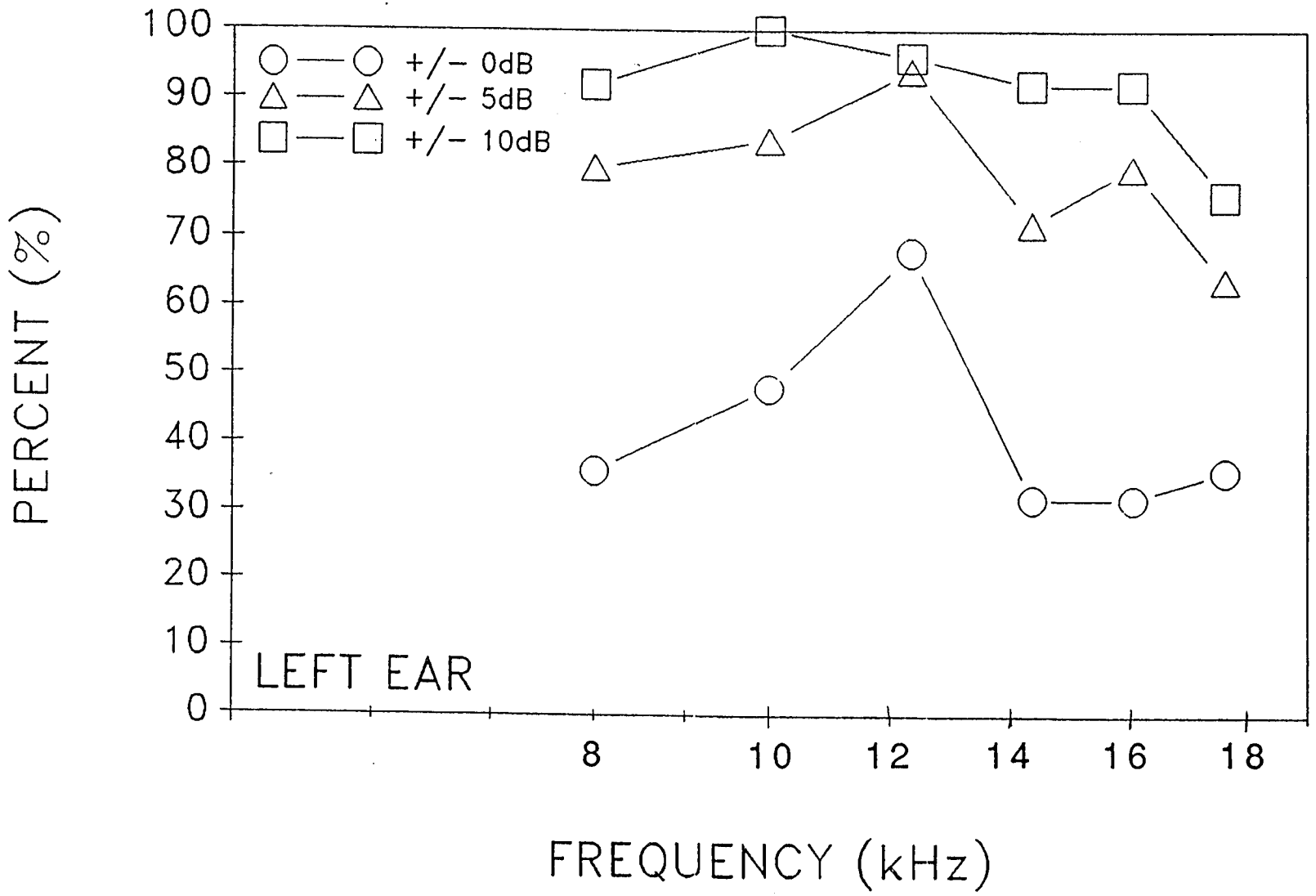
# FIGURE 2: MEAN THRESHOLDS OF HOSPITAL ROOM TEST AND RETEST



# FIGURE 3: PERCENT OF CASES AT ±0 dB, ±5 dB, ±10 dB MEAN THRESHOLD DIFFERENCES FOR HOSPITAL ROOM TEST AND RETEST



# FIGURE 4: PERCENT OF CASES AT ±0 dB, ±5 dB, ±10 dB MEAN THRESHOLD DIFFERENCES FOR HOSPITAL ROOM TEST AND RETEST



# FIGURE 5: MEAN THRESHOLDS OF PRESENT STUDY AND SCHECHTER ET AL. STUDY

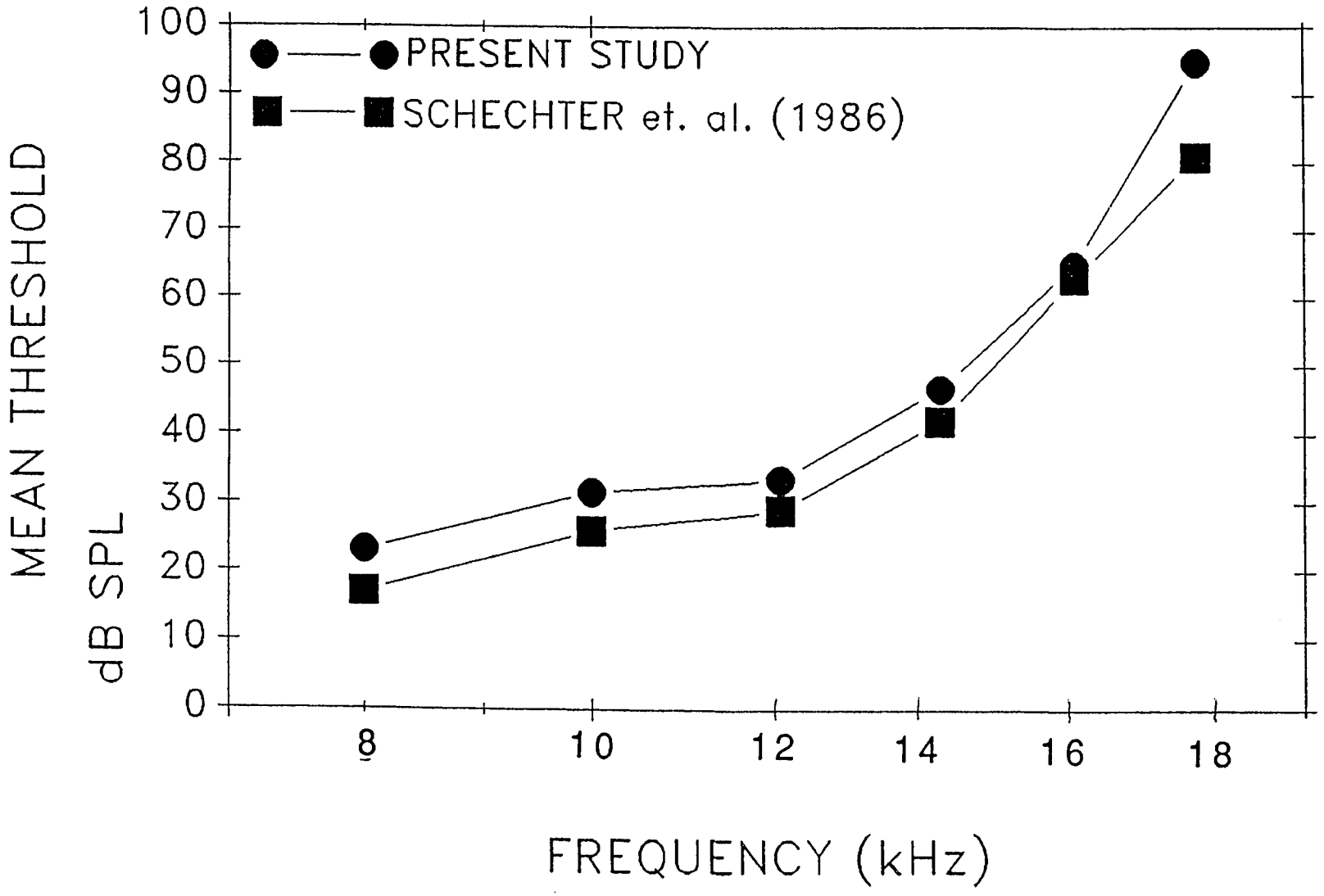


TABLE 1: CALIBRATED REFERENCE LEVELS IN dB SPL

| FREQUENCY | CALIBRATED REFERENCE LEVEL (with 100 dB SPL input) |
|---|---|
| 8 kHz | 123 |
| 9 kHz | 125 |
| 10 kHz | 127 |
| 11 kHz | 129 |
| 12 kHz | 128 |
| 13 kHz | 133 |
| 14 kHz | 135 |
| 15 kHz | 139 |
| 16 kHz | 142 |
| 17 kHz | 145 |
| 18 kHz | 157 |

NOTE: The calibrated levels do not reflect adjustment for microphone correction factor and frequency correction factor.